NATIONAL ACADEMY OF SCIENCES

Number 31 • January 1960

IGY BULLETIN

A monthly survey of programs and findings of the International Geophysical Year and the International Geophysical Cooperation–1959 as related primarily to United States programs

Radiation Studies on the South Polar Snowfield

This report is based on material prepared by Kirby J. Hanson, of the US Weather Bureau. A more detailed account will appear in the Journal of Geophysical Research, *March 1960.*

To an observer at the IGY Amundsen-Scott South Pole Station, the polar plateau appears flat and unbroken as far as the eye can see in all directions. The sun is above the horizon continuously for six months, and the snow-surface temperature remains below 0°C throughout the year. All of these factors make the geographic South Pole a most suitable place to measure the solar and terrestrial radiation fluxes, and associated energy exchanges, peculiar to a high-altitude (9280 feet above mean sea level), high-latitude snowfield. The first such observations at the South Pole were made during the IGY. This report presents preliminary results of these studies.

The IGY radiation program at the South Pole Station was established by E. C. Flowers during the 1956–57 season. It was continued in 1957–58 by Kirby J. Hanson with the assistance of D. M. Baulch and A. E. Jorgensen. Harry Wexler and T. H. McDonald contributed helpful suggestions and advice. All of the above are personnel of the US Weather Bureau.

Instrumentation

The radiation instruments were located about 300 yards from the station. Direct solar radiation was measured with an Eppley normal-incidence pyrheliometer. This instrument, mounted about one and one-half meters above the snow surface, was able to "follow the sun" continuously during the six-month south polar day. However, since the sun itself occupies only a small portion of the total area that the instrument "sees," cloudiness increases the ratio of diffuse sky to direct solar radiation; thus, the error in measuring direct solar radiation also increases. For this reason, measurements of direct solar radiation were made during clear sky conditions only.

Total global radiation, or the total radiation (short-wave) falling on a unit area of horizontal surface, was measured by an Eppley horizontal-incidence pyrheliometer, or pyranometer, about two meters above the snow surface. In order to measure the total global radiation reflected from the snow surface, an identical Eppley horizontal-incidence pyrheliometer was inverted and mounted five meters above the snow.

Also used were the Beckman and Whitley total hemispherical radiometer (effective pyranometer) and net exchange radiometer (radiation balancemeter). The total hemispherical radiometer measures the total global radiation plus atmospheric (long-wave) radiation downward. This instrument is unaffected by the type of surface beneath it, since it only measures the radiation from the hemisphere above. The net exchange radiometer on the other hand is affected by the snow-surface temperature and albedo (reflectivity) since it measures the shortwave radiation balance (incoming-outgoing) plus the long-wave balance (incoming-outgoing).

Radiation Observations

Solar Radiation: Incoming solar radiation has two components: diffuse sky and direct.

Figure 1 shows the relationship between

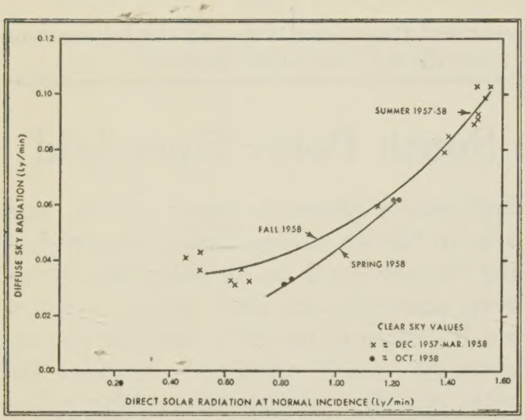

Fig. 1. *Plot of Diffuse Sky Radiation Against Direct Solar Radiation at Normal Incidence for Clear-Sky Conditions at Amundsen-Scott Station.*

normal-incidence direct solar radiation and diffuse sky radiation at the South Pole. Apparently, there is less scattering of the solar beam in spring than in fall. By converting direct normal-incidence solar radiation to horizontal-incidence radiation the mean diffuse, clear-sky radiation can be shown as a function of the direct solar radiation on a horizontal surface (Fig. 2).

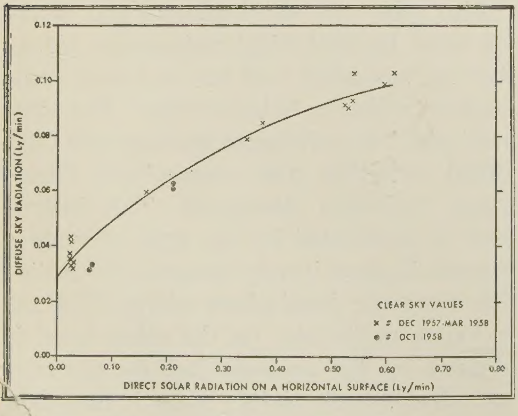

Fig. 2. *Plot of Diffuse Sky Radiation Against Direct Solar Radiation on a Horizontal Surface for Clear-Sky Conditions at Amundsen-Scott Station.*

This relationship gives a good estimate (0.03 ly/min) of the diffuse, clear-sky radiation at sundown, i.e., when the direct solar radiation is zero. (One langley, ly, is equal to one calorie per square centimeter.)

At the South Pole, diffuse sky radiation is about 14% of the total global radiation in mid-summer. G. H. Liljequist, some years ago, found the minimum value of the ratio of diffuse sky to total global radiation to be 17% at Maudheim (71°S) on the coast of Antarctica. On the Greenland Ice Cap near 78°N, M. Diamond and R. W. Gerdel found a ratio of 19%.

Comparisons and Relationships of Radiation Measurements

In Figure 3, direct solar radiation at normal incidence (curve 1), the vertical component of direct solar radiation (curve 2), total global radiation (curve 3), dif-

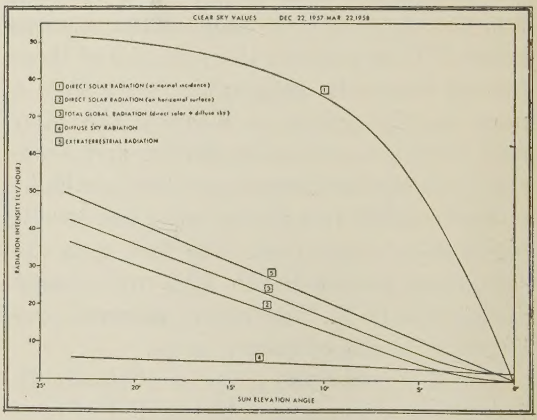

Fig. 3. *Solar Radiation, Amundsen-Scott Station, December 22, 1957—March 22, 1958 (clear-sky values).*

fuse sky radiation (curve 4), and extraterrestrial radiation, i.e., the solar radiation falling on a horizontal surface outside the earth's atmosphere (curve 5), are plotted against various sun elevation angles. Many applications and comparisons of these radiative fluxes can be made; a few are discussed below.

Atmospheric Transmission of Solar Radiation: "Atmospheric transmission coeffi-

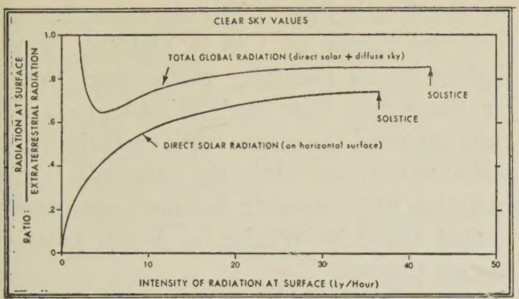

Fig. 4. *Transmission Coefficient Curves for Direct Solar and Total Global Radiation, Amundsen-Scott Station, Summer 1957-58 (clear-sky values).*

cient" is here defined as the ratio of radiation observed at the surface to extraterrestrial radiation. Figure 4 shows the transmission coefficients for direct solar and total global radiation as a function of the intensity of their respective fluxes observed at the surface. It can be seen that the transmission coefficient for the direct solar beam is approximately .75 near the summer solstice, decreasing to zero at sundown. This large transmission coefficient near solstice indicates low atmospheric turbidity. The transmission coefficient for the Pole Station at the summer solstice is approximately the same as that found by H. Kimball for the same relative air mass at Mt. Whitney, California, approximately 5250 feet higher than the Pole Station. Kimball also found equal transmission coefficients for Spitzbergen and Mt. Wilson, California. The difference in their altitudes is approximately 5600 feet.

The total global radiation curve indicates what percentage of the radiation available per unit area at the top of the atmosphere will finally reach an equivalent area on the surface, regardless of the manner in which it arrives—diffusely scattered, reflected, or direct. Total global radiation is about 85% of the extraterrestrial radiation with clear skies in mid-summer.

Depletion of solar radiation, either by intervening cloudiness or by clear air, is smaller in polar regions than in middle latitudes. Moreover, in polar regions, cloud conditions may arise in which the diffuse sky component of radiation on a particular unit area of the surface may increase while there is no depletion of the direct solar beam. The result is a sizeable increase in total global radiation—large enough, at times, so that the total global radiation *may exceed* the extraterrestrial radiation (see Fig. 5). Total global radiation also exceeds extraterrestrial radiation at sundown.

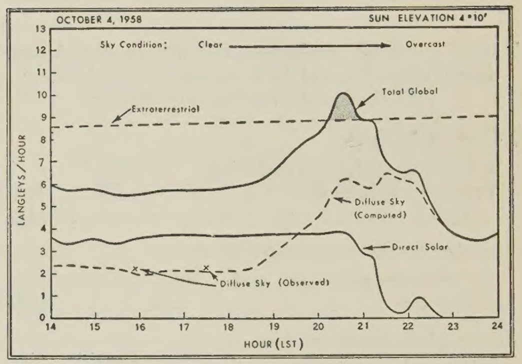

Fig. 5. *Anomalous Total Global Radiation, Amundsen-Scott Station, October 4, 1958.*

Atmospheric Solar Radiation Balance: The curves in Figure 4 may be used to estimate directly the solar radiation balance of the south polar atmosphere. If this is done for a particular time (in this case the summer solstice), and acceptable values for atmospheric scattering and absorption by water vapor, dust, and dry air are used, the depletion of extraterrestrial radiation is accomplished as follows: 74% is reflected back to space; 13% is absorbed by water vapor, dust, and dry air (the latter includes O_2, O_3, and CO_2); 13% is absorbed by the snow surface. (See Table 1, next page, for a more complete break-down of the south polar radiation balance.)

Even though the polar plateau receives more extraterrestrial radiation than is possible anywhere else on earth, only a small percentage is finally absorbed by the snow surface—13% (or 148 ly/day). By comparison, Sigmund Fritz, in 1951, found that

in middle latitudes during cloudless conditions about 80% of the daily energy entering the outer atmosphere reaches the ground. Assuming an albedo of roughly 10%, except in snow-covered areas, he concludes that about 72% of this energy, or about 450 ly/day, is absorbed by the earth's surface. This value is about 3 times as large as that found at the South Pole, even when maximum insolation is being received and the day is twice as long as a middle-latitude day.

TABLE 1—*Solar Radiation Balance in the Atmosphere (Clear Sky) at IGY Amundsen-Scott South Pole Station during Summer Solstice*

Reflection to Space		
From atmosphere (scattering)	= 17%*	
From snow surface	= 57%	
Total	=	74%
Absorbed by the Atmosphere		
By water vapor, dust, and dry air	=	13%
Fluxes at the Snow Surface		
Diffuse sky radiation	= 13%	
Direct solar radiation	= 78%	
Total global	= 91%	
Reflected global	= 78%	
TG-RG	= 13%	
Absorbed by the Snow Surface	=	13%
Total	=	100%

* All values represent approximate percentages of extraterrestrial radiation.

Turbidity Factor: The turbidity factor is a simple index of the dust and water-vapor content of the atmosphere, originally expressed as the number of clean, dry atmospheres needed to produce the attenuation of solar radiation found in a real atmosphere containing water vapor and dust. By definition, the turbidity factor can never be less than 1.0.

A turbidity factor of 1.40 was found for the South Pole Station during the summer. Direct comparison with other stations at or near sea level can be made. Kimball found a turbidity factor of 1.41 for Spitzbergen in summer, almost exactly the same as that for the South Pole. Little America had a turbidity factor of 1.68 in October. This slightly larger turbidity factor than those for the South Pole and Spitzbergen suggests the need for future work on turbidity-factor variations within the Antarctic. This variation will probably be small compared to that found by Wexler for North American air masses.

Albedo: In terms of its albedo, the surface of the polar plateau may be considered a "new" snow surface, since it is not subjected to melting or contamination, although undergoing occasional drifting. The albedo percentages for the six summer months are as follows: the first two sunlit months (referred to as "spring" for purposes of comparison), 77% when clear, 84% when cloudy; the second two ("summer"), 74–83% when clear, 80–88% when cloudy; and the last two ("fall"), 87% when clear, 93% when cloudy.

The 10% difference between spring and fall may be attributed to the changing character of the snow surface. In spring, the surface is rough owing to wind action during the winter night, when wind speed averages about 15 knots. In middle or late summer, however, increasing precipitation and decreasing wind velocity (to about 8 knots) tend to smooth the surface so that by fall little or no trace remains of the wind-induced surface patterns of the previous winter.

Thus, the albedo is near 80% in the spring, remaining constant through early summer. Then, as the surface becomes smoother, albedo increases to about 85% in mid-summer, and finally averages about 90% in the fall. Cloudy-day albedos appear to be 5–7% higher than those for clear days.

On rare occasions during the summer, the sky may become overcast with a low, *uniform* cloud cover (but not so low as to restrict surface visibility). On such occasions, multiple reflection of sunlight between the cloud base and the snow surface

diffuses the light so that the drifts are illuminated equally on all sides, causing all shadows to disappear and surface features, including the horizon, to become indistinguishable. This condition is commonly known as a "whiteout."

On other days, however, the sky may be overcast with a *non-uniform* cloud base, and no whiteout is present. Snow-surface albedos on these two types of overcast days are nearly identical, averaging about 1% higher during whiteout conditions.

"Warm" Cloud Effect: During the World Meteorological Interval (WMI) of June 15–24, 1958, the sky remained clear continuously for eight days and the snow-surface temperature reached a low of —104°F. The polar plateau was in continuous darkness during the period and, therefore, no solar radiation was received. Hence, the interval was ideal for studying, under conditions of extreme cold, the incoming flux of long-wave radiation from the atmosphere only .

During the first eight days, the hemispheric radiation averaged about 5 ly/hr—a typical value under conditions of clear skies, low atmospheric moisture content, and low surface temperatures. With an increase in cloudiness, precipitation, and surface wind on June 23, there was a marked increase in both surface temperature and hemispheric radiation.

The short-period variations of hemispheric radiation and snow-surface temperature were about equal during clear periods, but in cloudy weather the hemispheric-radiation variations were considerably larger than those of snow-surface temperature. This suggests that hemispheric radiation does not exhibit a singular control over snow-surface temperature. Two sensible heat fluxes exhibit a partial control, however—the flux of eddy diffusion and the subsurface heat flux.

Sensible Heat and Radiant Energy Fluxes: During the 18-month IGY period, temperatures at the South Pole (at about two meters above the ground) fell below −100°F on five separate days. These minima were approximately —100°, —101°, and, on three days, —102°F. The minimum temperature of —102° is apparently a "favored" equilibrium temperature for the present circulation-temperature regime at the geographic South Pole.

Examination of a period when this temperature extreme occurred shows how the radiant-energy and sensible-heat fluxes contribute toward an energy balance at the snow-atmosphere interface. A period in mid-September when the 2-meter temperature reached —101.7°F was selected for study (Fig. 6). With a wind of 15 knots and scattered cloudiness, the temperature had dropped to its minimum value by the middle of the period. Increased cloudiness raised the temperature to —90°F by the end of the period.

As shown by C, in Figure 6, net radiation, or the radiant energy balance at the snow surface, represents a net loss of energy at the snow surface during this mid-September period. The radiant energy balance does not exhibit a singular control over snow-surface temperature, however, since the sensible heat fluxes—(D) eddy diffusion (or turbulent transport of heat from air to surface) and (E) subsurface flux (or heat conducted upward from the snow)—also contribute to the surface energy balance.

During the first of the four periods, C represents an energy loss and fluxes D and E represent gains. If no other energy exchange processes were operating at the surface, one would expect C to equal D plus E. However, C is found to be slightly larger than D plus E; hence, there is a small negative remainder (—0.007 ly/min). This remainder is shown as F (net flux), and during the first period could have resulted from sublimation of the surface at the rate of 0.15 mm of water/cm^2/day. During the next two periods, F was zero, indicating that the net sublimation was about zero. During the last period, F was

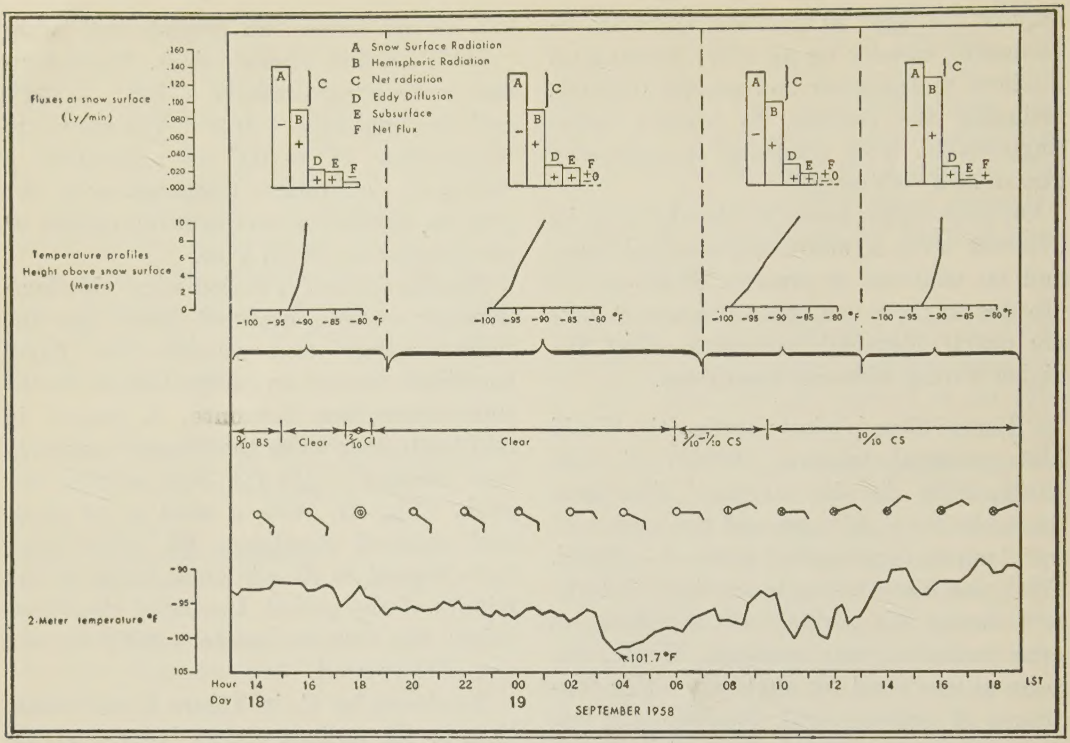

Fig. 6. *Surface Meteorological Conditions and Radiant and Sensible Heat Fluxes at Amundsen-Scott Station, September 18-19, 1958.*

slightly positive (+0.002 ly/min) and indicates deposition at the rate of 0.04 mm of water/cm²/day.

The four consecutive balance observations shown in Figure 6 permit study of the change in the fluxes with time, bearing in mind that the snow-surface radiation is a function of snow-surface temperature only. Hemispheric radiation was relatively small (0.09 ly/min) during the first three periods, but increased (to almost 0.12 ly/min) as the sky became overcast. As a result, the net radiation, ranging from —0.04 to —0.05 ly/min during the clear, cold period, approached zero as the value of the warm cloud radiation approached that of the snow-surface radiation.

It can now be seen how the sensible heat fluxes make up the loss in radiant energy. During the first two periods, the two sensible heat fluxes were nearly equal in magnitude; however, as the temperature began to increase, the subsurface heat flux decreased to about half that owing to eddy diffusion. By the last period, the air temperature had increased such that the net flux of heat was *into* the snow surface rather than *out of* it. The eddy-diffusion flux was still large, since no decrease in surface wind was observed. In fact, it was larger than the net loss of radiant energy (C), and so accounts for the flux into the snow (E).

The above situation may be quite typical of the warming on the polar plateau when relatively warm clouds (up to 50°F warmer than the snow surface), acting as "black body" radiators, are introduced after a clear, cold period. This warm-cloud effect occasionally causes net radiation to approach, and sometimes exceed, zero. When net radiation is zero, the heat conducted from the atmosphere to the snow surface is then conducted downward into the snow. Thus, it is seen that the rapid

warming of the south polar plateau by warm cloud radiation is aided by the molecular and eddy conduction of heat from the air.

Conclusions

F. Loewe estimated the net radiation loss for the Antarctic inland ice as 100 ly/day. At Port Martin on the coast of Antarctica Loewe found in 1951–52 a net loss of 20 ly/day, almost the same as the net loss of 25 ly/day found by Liljequist at Maudheim, another coastal station, in 1949–52. For the IGY period, the radiation loss at the South Pole is estimated at 35 ly/day, or less than half that estimated by Loewe for inland areas.

The south polar plateau is a radiative cold source. The estimated magnitude of the heat loss is large enough to cool the first 10 meters of snow by about 100°C per year, if radiation alone controlled the energy balance at the surface. Observations have shown that the annual temperature variation at a depth of 10 meters is less than 1°C; therefore, it is apparent that vertical and horizontal heat transport represent an energy gain nearly equal to the net radiation loss.

Intensity Variations of Primary Cosmic-Ray Components

The following report is based on material supplied by Peter Meyer, of the Enrico Fermi Institute for Nuclear Studies, University of Chicago. A more detailed account appeared in The Physical Review, *September 15, 1959.*

Two series of high-altitude IGY balloon flights were made by University of Chicago investigators in 1957 and 1958 to study short-term intensity variations of the proton (H^+) and alpha-particle (He^{++}) components of the primary cosmic-ray flux, and their interrelationships. The experiment sought to explain the changes observed in total cosmic-ray flux by obtaining more information on intensity variations of these different components of the primaries. (Protons make up approximately 86% of primary cosmic rays, alpha particles 13%, and still heavier nuclei 1%. The secondary flux, formed by interaction of primaries with atmospheric particles, includes secondary protons and nucleons, pi mesons [both charged and neutral], and heavier mesons.)

Bulletin No. 15 presented the results of two of the earlier flights made as part of this experiment. This report reviews the experimental techniques, results, and conclusions of the entire series. The studies were directed by Peter Meyer. Other University of Chicago personnel helped in building and maintaining the equipment, in the launching, and in computation and data processing.

Variations in the total cosmic-ray intensity have been observed for many years, mainly by permanently installed cosmic-ray monitors at ground stations capable of recording intensities over long periods of time. More recently, these ground observations have been complemented by measurements with instruments carried by aircraft, balloons, rockets, satellites and space probes.

Past studies have shown that most variations of cosmic-ray intensity occur in the

primary flux and do not result from local influences such as geomagnetic or meteorologic effects. It has also been demonstrated that the mechanisms giving rise to such variations must be solar-controlled and must operate within or near the solar system. Although extensive studies have been carried out to account for the observed phenomena, no single complete explanation has as yet been found. However, a rather close correlation was noted between changes in the alpha-particle and proton intensities, and it was concluded that the same mechanism is responsible for the intensity modulation of both.

Detailed comparisons of the variations in alpha-particle and proton fluxes have special value in studies of primary cosmic-ray variations. If, for example, the total flux of low-energy primaries is of galactic origin and the intensity modulation results from disordered magnetic fields within the solar system, very similar changes for each rigidity interval (see below) of both protons and alpha particles would be expected. On the other hand, if solar production of particles with cosmic-ray energies plays a more important role than is generally assumed, variations in the ratio of the alpha-particle flux to the proton flux are likely to occur.

The Experiment

The technique used involved a combination of scintillation and Cerenkov counters, allowing discrimination between alpha particles and protons. This technique, first described by F. B. McDonald, is capable of measuring the alpha-particle flux over an appreciable energy range. Using lucite (a transparent synthetic resin) with an index of refraction of 1.5 in the Cerenkov counter, alpha particles with energies down to 450 million electron volts per nucleon (or 1800 mev/particle) are easily distinguished from low-energy protons.

Since the investigation was concerned primarily with short-term variations—the 27-day variation, the sudden Forbush-type intensity decreases accompanying magnetic storms, and, possibly, 24-hour variations—the ground-level neutron monitor at Chicago was used to choose appropriate times to make observations. Balloons carrying the instrumentation described were sent to altitudes of about 100,000 feet (near the "top of the atmosphere" for cosmic-ray effects) in two series of measurements at high geomagnetic latitudes. A total of seven successful flights were made, of which five are included in the present analysis. Of the first series, flown from Prince Albert, Saskatchewan, Canada, flights of August 16, August 30, and September 16, 1957, are discussed; of the second series, from Neepawa, Manitoba, Canada, flights made on July 12 and 22, 1958, are analyzed. Prince Albert is at geographic latitude 53° 13′ N, 105° 41′ W, and Neepawa is at 50° 16′ N, 99° 27′ W. The balloons remained at peak altitude for about 8 hours during the 1957 flights and for about 20 hours in the 1958 flights.

The geomagnetic rigidity cut-offs for Prince Albert and Neepawa are 0.6 and 0.7 billion electron volts, respectively. (Magnetic rigidity = momentum/charge, and measures a particle's resistance to deflection by a magnetic field.) These rigidity cutoffs are well below the lower rigidities of the spectrum of primary cosmic rays, and it may be expected that the small changes in latitude during the flights would not noticeably influence the flux measurements. The cut-off for any geomagnetic latitude represents the lowest rigidity normally capable of penetrating the geomagnetic field at that latitude: high-energy particles, with correspondingly high rigidities, can penetrate the earth's field at the equator, but very low energy particles can penetrate only in the vicinity of the magnetic poles.

The 1957 observation period showed the greatest cosmic-ray intensity changes for the entire year. About September 1, in particular, solar activity was very high, resulting in large intensity variations.

TABLE 2

Date	Climax Neutron Monitor Intensity	Average Pressure During Flight (mm Hg)	Total Number of Protons Counted in Flight	Proton Flux[1] Corrected for 13.5 g/cm²	Total Number of α-Particles Counted in Flight (E > 530 Mev/nucleon)	α-Particle Flux[1] Corrected for 13.5 g/cm² and Background (E > 530 Mev/nucleon)	α-Particle Flux at the Top of the Atmosphere (E > 560 Mev/nucleon)
Aug. 16, '57	2841 ± 1%	11.3	41,940	1910 ± 2%	2,275	103.0 ± 4%	136.4 ± 9%
Aug. 30, '57	2480 ± 1%	10.2	48,546	1662 ± 2%	2,265	94.0 ± 4%	124.4 ± 9%
Sept. 16, '57	2780 ± 1%	10.2	51,424	1921 ± 2%	3,224	115.1 ± 4%	153.9 ± 9%
July 12, '58	2709 ± 1%	9.4	75,828	1627 ± 2%	5,094	103.7 ± 3%	138.0 ± 8%
July 22, '58	2694 ± 1%	9.0	80,701	1588 ± 2%	5,836	105.2 ± 3%	140.1 ± 8%

[1] All flux figures in particles per square meter per steradian (unit solid angle) per second

Results

Values of the proton and alpha-particle fluxes for the five selected balloon flights were compared with the total cosmic-ray intensity measured with a ground-based neutron monitor at Climax, Colorado (see Table 2). All alpha-particle data were normalized to an altitude corresponding to an atmospheric pressure of 13.5 gm/cm² (about 96,500 feet), and corrections were made for the general radiation background in the alpha-particle region. A similar procedure was used to correct proton-flux values to the same level.

Alpha-Particle and Proton Flux Changes on August 30, 1957: Measurements of the alpha-particle and proton fluxes were made before, during, and after a large Forbush-type intensity decrease on August 30, 1957. (Forbush decreases frequently accompany geomagnetic storms, following a solar flare by about a day; these decreases are thought to be caused by the cloud of ionized gas hurled outward by the flare.)

Using for reference the values obtained on August 16, about two weeks before the Forbush decrease, Table 3 compares the changes in total intensity as recorded at three neutron-monitor stations, with balloon data on proton intensity, and intensity of alpha particles with energies greater than 530 mev/nucleon at the altitude of observation. It can be seen that, during this period, relatively similar changes occurred in the average intensities of both protons and al-

TABLE 3

	Balloon Data		Neutron Monitor Station Data		
Date	Proton Flux % Change	α-Particle Flux % Change E > 530 Mev/nucleon	Sulphur Mountain R = 0.98 BV	Climax R = 2.71 BV	Sac. Peak R = 4.7 BV
Aug. 16, '57	0	0	0%	0%	0%
Aug. 30, '57	−13.0 ± 2	−9 ± 4	−12.4%	−12.7%	−7.9%
Sept. 16, '57	+0.6 ± 2	+12 ± 4	−4.1%	−2.1%	—
July 12, '58	−14.8 ± 2	+1 ± 4	−7.3%	−4.8%	−1.6%
July 22, '58	−16.8 ± 2	+2 ± 4	−6.6%	−5.2%	−2.8%

pha particles (within the accuracy range of the experiment). During the two weeks following the decrease, the intensities of both components returned to high values, with the alpha-particle increase substantially exceeding that of the protons. When the relative intensity changes observed at the various neutron-monitor stations are compared, it appears that for particles with rigidities of less than 4 bev very little dependence on rigidity existed in this event.

To investigate the possible rigidity dependence of the alpha-particle variation, the flux was divided into two intervals: the first included alpha particles with energies between 450 and 960 mev/nucleon and the second included those with energies exceeding 960 mev/nucleon. Table 4 lists the alpha-particle fluxes within these energy intervals for the five flights. There appears to be no evidence for a strong dependence on either energy or rigidity. The investigators therefore conclude that, within the total energy range covered by this experiment, a common modulation mechanism operated on both the alpha-particle and the proton fluxes during the large Forbush decrease of August 30, 1957.

TABLE 4

Date	α-Particle Flux 450–960 Mev/nucleon[1]	α-Particle Flux >960 Mev/nucleon[1]
Aug. 16, 1957	33 ± 6%	85 ± 5%
Aug. 30, 1957	31 ± 6%	72 ± 5%
Sept. 16, 1957	38 ± 6%	87 ± 5%
July 12, 1958	37.6 ± 5%	77.5 ± 4%
July 22, 1958	35.1 ± 5%	81.8 ± 4%

[1] Corrected for 13.5 g/cm² and shown in particles per square meter per steradian (solid unit angle) per second

The rigidity relationship of this particular event differs strikingly from that of cosmic-ray variations related to the 11-year solar cycle, adding to increasing evidence that the mechanisms responsible for these two types of intensity variations are not closely related. The lack of dependence on rigidity of the Forbush decrease can be explained on the basis of modulation of the flux by disordered magnetic fields. It appears that the scale of the disordering is equal to the Larmor radius (the radius of deflection of a particle in a magnetic field) at the energy below which the lack of dependence on rigidity occurs. Aircraft measurements by J. A. Simpson, made before, during, and after a Forbush decrease on August 18, 1951, also showed this lack of dependence on rigidity in the same rigidity interval. (The present experiment was not capable of discriminating between energy dependence and rigidity dependence of the variations measured.)

Intensity and Energy-Spectrum Changes Between 1957 and 1958

Noticeable changes occurred in the intensity and energy spectrum of primary cosmic rays in the interval between the two series of balloon flights. In Table 3, decreases in neutron intensity of about 7% at Sulphur Mountain, Canada, and about 5% at Climax, Colorado, are evident between 1957 and 1958. For the same interval, a drop of about 15% in proton intensity can be seen. (K. B. Fenton reports that a decrease in intensity comparable to the proton decrease was observed by balloon-borne neutron equipment at high altitude and latitude during this period.)

A strong dependence on rigidity is indicated by the above changes, in contrast to the lack of rigidity dependence during the Forbush decrease of late August and early September 1957. Moreover, aircraft measurements have shown that the rigidity cutoff of the primary cosmic-ray spectrum changed from low to higher values between summer 1956 and early 1958.

These changes in the low-energy end of the cosmic-ray spectrum and in rigidity dependence are in accord with the 11-year cosmic-ray-intensity cycle. (Observations over the past few decades have shown that cosmic-ray intensity varies inversely with

the 11-year sunspot cycle: when sunspot activity reaches a peak in the cycle, cosmic-ray intensity falls off; when solar activity is at a minimum, cosmic-ray intensity increases.)

Decreases comparable to those described for protons and neutrons were not found during the 1957–1958 interval in the flux of primary alpha particles with energies greater than 530 mev/nucleon. This flux remained virtually unchanged. Hence, the ratio of the proton flux to the alpha-particle flux, at a height level of 13.5 gm/cm^2, decreased from an average of 17.6:1 in 1957 to 15.4:1 in 1958.

However, when the alpha-particle flux was divided into two energy levels—particles with energies of 450–960 mev/nucleon and particles with energies greater than 960 mev/nucleon (see Table 4)—it was found that intensity decreased in the higher-energy group, while the lower-energy flux increased. (Statistical accuracy of the two-energy-level study is lower than that of the flux measurement of particles with energies greater than 530 mev/nucleon.) The behavior of the alpha-particle flux at the two energy levels is exactly opposite that to be expected on the basis of the proton-flux data.

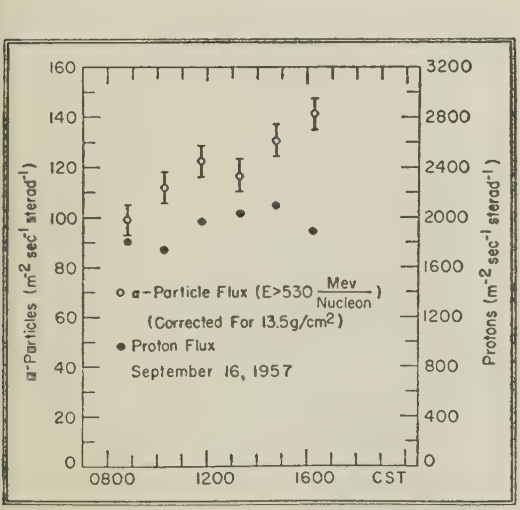

Fig. 7. *Increase in Alpha-Particle Flux With Time.*

Rapid Variations in the Alpha-Particle Flux

To study in detail the primary cosmic-ray flux as a function of time, the flight periods were divided into 90-minute intervals. During all of the 1957 measurements, an increase in the alpha-particle flux with time was apparent, but it was not accompanied by a similar variation in proton flux. This effect was most noticeable in the September 16 measurements (see Fig. 7.) As all of the 1957 flights were launched in the early morning hours, they represent about the same periods of local time.

The alpha-particle increase was observed not only for particles with energies exceeding 530 mev/nucleon, but also, with comparable amplitude, in both the 450–960 mev/nucleon energy level and in the level including particles with energies above 960 mev/nucleon. (The total cosmic-ray intensity was measured independently in another experiment by F. Jones and K. Yates. Using a vertical geiger-counter telescope, they found that the time relationship of the total intensity was the same as that of the proton flux.)

A similar increase in the alpha-particle flux without a corresponding increase in protons was also observed on March 13, 1956, by F. B. McDonald. This earlier measurement, like those of the present experiment, also was made during a large Forbush decrease in total cosmic-ray intensity accompanying a period of enhanced solar activity.

This increase in alpha-particle intensity while the proton flux remains relatively unchanged is tentatively attributed by the University of Chicago investigators to a 24-hour variation in the alpha-particle flux or to an anisotropy—a difference in the properties of the flux with direction. Further studies are planned to test this hypothesis.

In order to investigate this effect in greater detail, the 1958 flights, during a period when no enhancement of solar activity took place, remained at peak altitude for about 20 hours. However, no similar

independent increase in alpha-particle intensity was observed.

Absolute Flux of Primary Alpha Particles

Owing to the greater length of time of each measurement and to the wider angle of coverage of the equipment, the total number of alpha particles counted during each flight of the present investigation is substantially higher than in any previous experiment. It was therefore thought worthwhile to use this data to determine the absolute flux of primary alpha particles at the top of the atmosphere—in particles per square meter per steradian, or unit solid angle, per second.

The results of these computations are shown in the last column of Table 2, which gives the flux of all primary alpha particles with energies greater than 560 mev/nucleon after first accounting for an energy loss of 30 mev/nucleon during the particles' traversal of the residual atmosphere and the measuring equipment.

Summary and Conclusions

Two series of measurements of the proton and alpha-particle fluxes of the primary cosmic radiation were made in 1957 and 1958 using balloon-borne scintillation and Cerenkov counters. On one of the flight series, measurements were obtained before, during, and after a large Forbush-type intensity decrease which occurred on August 30, 1957. The following conclusions were arrived at by the investigators after analysis of the flight data:

(1) Since both the proton and alpha-particle fluxes showed the same relative variation during the Forbush decrease, it is postulated that a common modulation mechanism operated in the same way on both components. No energy dependence was found for the intensity variations associated with this event.

(2) The relative proton-intensity change at altitude was about the same as the change observed by neutron monitors in Colorado and Canada; hence, virtually no rigidity dependence was noticeable in this Forbush decrease up to a rigidity of 4 bev.

(3) Comparison was made of the proton intensity decrease of about 15% at high altitude and latitude between measurement days in 1957 and 1958 with decreases of 7% and 5%, respectively, at neutron-monitor stations in Canada and Colorado in the same period; a change in the low-energy end of the primary proton spectrum was indicated. This change is believed associated with the primary cosmic-ray variation related to the 11-year solar-activity cycle.

(4) Unlike the proton flux, the flux of alpha particles with energies greater than 530 mev/nucleon remained unchanged between 1957 and 1958. However, division of the alpha-particle flux into a higher and a lower energy group showed (with less certain statistical accuracy) a decrease in intensity of the high-energy group and an increase in the low-energy group. This result is opposite that to be expected from the proton data.

(5) Increases in alpha-particle flux for several hours during 1957 daylight flights (while solar activity was very high) not accompanied by corresponding decreases in the proton flux are tentatively attributed to a 24-hour variation in alpha-particle intensity.

(6) The independent hourly variation in alpha-particle intensity and the change in the ratio of the alpha-particle to the proton flux between 1957 and 1958 are not explainable by a common modulation mechanism for both components. Hence, it is suspected that primary alpha particles may occasionally be produced by the sun.

Solar Flares, Geomagnetic Disturbances, and WWA Decisions, Third Quarter 1959

This report is one of a series issued periodically throughout the IGY and IGC-59. See Bulletin No. 28 *and the Indexes to* Bulletins 1–24, *published in* Bulletins 12 and 24, *for earlier reports in this series.*

During the third quarter of 1959 (July 1—September 30), a general increase in geomagnetic activity was observed, as shown by the greater frequency, severity, and duration of disturbances. The most severe geomagnetic storm began on July 15 (see list below) and produced an A-index unsurpassed by that of any disturbance on record at WWA—the World Warning Agency. (The A-index is a daily magnetic-activity index which averages, on a linear scale ranging from 0 to 400, the eight daily 3-hourly indices; the 3-hourly indices are defined as one-half the average range, in gammas, of the most disturbed of the three components of geomagnetic force—vertical, horizontal, and declination—at standard geomagnetic stations.)

This severe storm of mid-July was associated with a great flare observed in an extremely active region in the vicinity of the sun's central meridian. Other major flares produced by this solar region were followed by the geomagnetic disturbances of July 11 and 17. A Special World Interval (SWI) was declared to accompany the great July 15 storm, while the other two, though predicted by the North Atlantic Radio Warning Service (NARWS), were accompanied by Alerts only.

These three geomagnetic disturbances in July, along with two severe disturbances in September for which SWI were declared (see list), were associated with 11 of the 16 whole-day radio disturbances of the quarter and with 33 of the 56 six-hour intervals of disturbed radio quality.

Of particular interest are the geomagnetic disturbances of July 23, August 20, and September 18. These storms occurred approximately 27 days apart and are the first readily identifiable recurrent storms since before the recent sunspot maximum, with which the IGY period was chosen to coincide. Several other disturbances during the quarter exhibited characteristics normally associated with recurring storms—gradual beginning, moderate intensity, and long duration—but no obvious 27-day pattern was discernible.

Only five of the 11 geomagnetic storms recorded during the quarter were preceded by the type of observable solar activity normally followed by storminess.

The following is a list of major solar flares (those evaluated as 3 or 3+ in importance by at least one observatory), geomagnetic disturbances, world-wide geophysical Alerts, and SWI for the third quarter of 1959:

Jun	27*	11xx**	Magnetic storm begins
	28	1600	Alert issued
	29	00xx	Magnetic storm ends
		0728	Magnetic storm begins
		1600	Alert issued***
Jul	1	00xx	Magnetic storm ends
	8	0818	Class 3+ flare; slow S-SWF†
	10	0210	Class 3+ flare; slow S-SWF
		0514	Class 3+ flare; G-SWF†
	11	1623	Magnetic storm begins
	12	13xx	Magnetic storm ends
		1600	Alert issued
		2152	Class 3 flare; G-SWF
	14	0325	Class 3+ flare; S-SWF†
		1400	Class 3+ flare; slow S-SWF
	15	0802	Severe magnetic storm begins
		1600	Alert issued; auroras expected SWI starts††
	16	12xx	Severe magnetic storm ends SWI finishes
		1308	Class 3 flare; S-SWF
		2114	Class 3+ flare; S-SWF
	17	1638	Severe magnetic storm begins
	18	1600	Alert issued; auroras expected
	19	06xx	Severe magnetic storm ends
	23	04xx	Magnetic storm begins
	27	2050	Class 3 flare; slow S-SWF
	28	03xx	Magnetic storm ends
	29	2020	Class 3 flare; slow S-SWF
Aug	15	14xx	Severe magnetic storm begins
	16	1600	Alert issued

18	1020	Class 3 flare; S-SWF
19	09xx	Severe magnetic storm ends
20	0410	Magnetic storm begins
	1600	Alert issued
21	1130	Class 3 flare
26	03xx	Magnetic storm ends
Sept 1	1650	Class 3 flare; S-SWF
2	0110	Severe magnetic storm begins
	0721	Class 3 flare; slow S-SWF
	1600	Alert issued
3	2159	Resurgence of magnetic storm beginning September 2
4	1600	Alert issued; auroras expected SWI starts
5		SWI finishes
6	10xx	Severe magnetic storm ends
18	21xx	Severe magnetic storm begins
19	1600	Alert issued
20	1600	SWI starts
21		SWI finishes
22	21xx	Severe magnetic storm ends
25	0045	Magnetic storm begins
	1600	Alert issued
28	08xx	Magnetic storm ends

Notes:

* Owing to publication schedules it was not possible to include in the preceding report (*Bulletin No. 28*) the last few days of the previous quarter; these are therefore included in the present report

** "xx" indicates gradual beginning or ending of a disturbance, following the hour indicated, such that the precise moment could not be determined

*** No ending times for alerts are issued, as was done during the IGY; this is now left to the discretion of individual observatories

† Symbols for ionospheric effects are defined as follows:

S-SWF—sudden short-wave fadeout and gradual recovery

Slow S-SWF—slow short-wave fadeout (taking 5-15 minutes) and gradual recovery

G-SWF—gradual disturbance; irregular short-wave fadeout or recovery, or both

†† SWI's, when warranted, start at the time the associated Alert is issued; they finish at the end of the day indicated

IGY Bibliographic Notes

This is the seventeenth of a series of bibliographic notes on IGY and IGC-1959 programs and findings. The references are selected largely from a bibliography under preparation in the Science and Technology Division of the Library of Congress. (An interim IGY bibliography, covering the period January 1951-August 1958, prepared by the Library and published by the Academy with support of the National Science Foundation, is available from the Academy, 2101 Constitution Avenue, N. W., Washington 25, D. C., for $1.00. The 64-page volume contains 704 references.)

W. C. Bain and E. D. R. Shearman: Observations on the U.S.S.R. Earth Satellites and the Study of Radio-Wave Propagation. *Proceedings of the Institution of Electrical Engineers.* Vol. 106, pt. B, no. 27. May 1959. Pp. 259–263. Diagr.

M. K. Vainu Bappu: Optical Tracking of Artificial Satellites. *Journal of Scientific and Industrial Research.* Vol. 17A, no. 12. Dec. 1958. Pp. 95–98. Illus.

R. Bateman, J. W. Finney, E. K. Smith, L. H. Tveten, and J. M. Watts: IGY Observations of F-Layer Scatter in the Far East. *Journal of Geophysical Research.* Vol. 64, no. 4. Apr. 1959. Pp. 403–405. Diagr.

S. K. Chakrabarty: Microseismic Work at the Bengal Engineering College. *Journal of Scientific and Industrial Research.* Vol. 17A, no. 12. Dec. 1958. Pp. 100–103. Illus.

Characteristics of the Antarctic Ice Sheet. *Geophysical Journal.* Vol. 2, no. 2. June 1959. Pp. 164–168.

Herbert Friedman: The Sun and the Upper Atmosphere. *Astronautics.* Vol. 4, no. 7. July 1959. Pp. 20–22, 55–56. Illus., diagr.

Kenneth W. Gatland: Rockets and Artificial Satellites in the IGY. *Spaceflight.* Vol. 1, no. 4. July 1957. Pp. 130–138. Illus.

Julian C. Holmes and Charles Y. Johnson: Positive Ions in the Ionosphere. *Astronautics.* Vol. 4, no. 7. July 1959. Pp. 30–31, 102–105. Illus., diagr.

Luigi G. Jacchia: Corpuscular Radiation and the Acceleration of Artificial Satellites. *Nature.* Vol. 183, no. 4676. June 13, 1959. Pp. 1662–1663. Diagr.

Takso Kawahara, Koji Nakanishi, Hiroshi Akiyama, Shuichi Aritake, Tanemoto Nijo, and Yasutaro Kato: Report of Telecommunication Subcommittee for the Japanese Antarctic Research Expedition. Part II. *Antarctic Record.* No. 5. Sept. 1958. Pp. 51–66. Illus., diagr., map.

D. C. King-Hele: Irregularities in the Density of the Upper Atmosphere: Results from Satellites. *Nature.* Vol. 183. Feb. 21, 1959. Pp. 527–529. Diagr.

Phillip Law: The IGY in Antarctica. *Australian Journal of Science.* Vol. 21, no. 9. June 21, 1959. Pp. 285–294. Map.

Jack T. Leininger: A Synchronized Smear Camera for Satellite Surveillance and Detection. *Photographic Science and Engineering*. Vol. 3, no. 4. July–Aug. 1959. Pp. 178–180. Illus., diagr.

E. R. Manring and H. B. Pettit: Photometric Observations of the 5577 A and 6300 A Emissions made during the Aurora of February 10–11, 1958. *Journal of Geophysical Research*. Vol. 64, no. 2. Feb. 1959. Pp. 149–153. Diagr.

A. P. Mitra: Ionosphere Disturbances at Low Latitudes. *Journal of Scientific and Industrial Research*. Vol. 17A, no. 12. Dec. 1958. Pp. 37–40. Diagr., refs.

K. N. Mathur and C. S. Rangan: Frequency and Time Standards at the National Physical Laboratory, New Delhi. *Journal of Scientific and Industrial Research*. Vol. 17A, no. 12. Dec. 1958. Pp. 83–87. Diagr.

John R. T. Molholm: Antarctic IGY Activities, 1956–1958. *Appalachia*. Vol. 25, no. 7. June 15, 1959. Pp. 404–406. Illus.

Frank Press: Some Implications on Mantle and Crustal Structure from G Waves and Love Waves. *Journal of Geophysical Research*. Vol. 64, no. 5. May 1959. Pp. 565–568. Diagr.

B. Ramachandra Rao and K. V. V. Ramana: Diurnal Variation of Ionospheric Absorption on 5.65 MC/S at Waltair during the IGY. *Journal of Scientific and Industrial Research*. Vol. 17A, no. 12. Dec. 1958. Pp. 56–58. Refs.

V. V. Somayajulu and N. Narayana Rao: Observations on Galactic Radiation at 30 MC/S. *Journal of Scientific and Industrial Research*. Vol. 17A, no. 12. Dec. 1958. Pp. 54–56. Diagr., refs.

F. J. Tischer: Doppler Phenomena in Space Communications. *IRE Transactions on Communications Systems*. Vol. CS-7, no. 1. May 1959. Pp. 25–30. Diagr.

R. S. Unwin: Movement of Auroral Echoes and the Magnetic Disturbance Current System. *Nature*. Vol. 183, no. 4667. April 11, 1959. Pp. 1044–1045. Diagr.

U. S. Army Ordnance Missile Command: Army Satellites—Teamwork Means Progress (An Historical Account). *Signal*. Vol. 13, no. 10. June 1959. Pp. 31–32.

Status of World Data Center A Reports

The activities of IGY World Data Center A include the publication of five series of special reports presenting data and results obtained in IGY and IGC-59 activities. The reports issued to date, and those now in press or in preparation, are listed below.

Reports in the General series and in the Rocket and Satellite series may be obtained from the Printing and Publishing Office, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington 25, D. C. Individual reports in these series are priced at $1.00 each; remittances must accompany orders of $1.00 or less. Discounts are available for standing orders for all titles in these three series; for quantity orders in excess of 5 copies of a single title; and to public and institutional libraries. Further information on these discounts may be obtained from the Academy.

In addition to continued publication of IGY-IGC results as they become available, it is tentatively planned to include in the Rocket and Satellite series many of the US papers presented at the First International Space Science Symposium, held in Nice, France, January 11–15, 1960, under the auspices of the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU).

General Report Series

1. Description of the Antarctic Circulation Observed from April to November 1957 at the IGY Antarctic Weather Central, Little American Station.
2. Preliminary Report on Expedition Downwind, University of California, Scripps Institution of Oceanography IGY Cruise to the Southeast Pacific.
3. Preliminary Reports on the IGY Pendulum, Gravimeter, and Seismological Programs at the University of Wisconsin.
4. Some Aspects of the Antarctic Atmospheric Circulation in 1958.
5. United States Program for the International Geophysical Year 1957–58.
6. United States Program for International Geophysical Cooperation—1959.
7. Interim Catalogue of Data in IGY World Data Center A.

Satellite Report Series

1. Processed Observational Data for USSR Satellites 1957 Alpha and 1957 Beta.
2. Status Reports on Optical Observations of Satellites 1958 Alpha and 1958 Beta.
3. Some Preliminary Reports of Experiments in Satellites 1958 Alpha and 1958 Gamma.
4. Observational Information on Artificial Earth Satellites.
5. Radio Observations of Soviet Satellites 1957 Alpha 2 and 1957 Beta 1.
6. Reports and Analyses of Satellite Observations.

7. Simplified Satellite Prediction from Modified Orbital Elements.
8. Ephemeris of Satellite 1957 Alpha 2 and Collected Reports on Satellite Observations.
9. Symposium on Scientific Effects of Artificially Introduced Radiations at High Altitudes.
10. The Determination of Ionospheric Electron Content and Distribution from Satellite Observations. (January 1960.)

Rocket Report Series

1. Experimental Results of the U. S. Rocket Program for the International Geophysical Year to 1 July 1958.
2. Flight Summaries for the U. S. Rocketry Program for the IGY, Part I: 5 July 1956–30 June 1958.
3. Flight Summaries for the U. S. Rocketry Program for the IGY, Part II: 23 May–31 December, 1958.
4. Magnetic Exploration of the Upper Atmosphere.
5. Upper-Air Densities and Temperatures from Eight IGY Rocket Flights by the Falling Sphere Method.

Glaciological Report Series

Reports in this series are available from IGY World Data Center A: Glaciology, American Geographical Society, Broadway at 156th Street, New York 32, New York. They are priced at $3.35 each ($3.00 + $0.35 for handling); standing orders may be placed. Additional reports in this series are now in preparation.

1. Preliminary Reports of the Antarctic and Northern Hemisphere Glaciology Programs.
2. Oversnow Traverse Programs, Byrd and Ellsworth Stations, Antarctica, 1957–58: Seismology, Gravity and Magnetism.

Solar Activity Report Series

Reports in this series consist of highly specialized tabulations of data, and are prepared primarily for distribution to other IGY WDC's and to participating observatories. Inquiries about the solar-activity reports should be addressed to IGY World Data Center A: Solar Activity, High Altitude Observatory, University of Colorado, Boulder, Colorado.

Preprinted from *Transactions, American Geophysical Union,* Vol. 50, No. 1, Mar. 1960

Subscription to the Bulletin is $2 for 12 issues beginning with the July 1959 issue (special rates: $1.50 to science teachers and students, and $1 for five or more mailed to a single address). For 36 issues beginning with July 1957, the rate is $6 ($5 and $4 special rates as above). Order from National Academy of Sciences, 2101 Constitution Avenue, Washington 25, D. C.